



Attitude Determination & Control System

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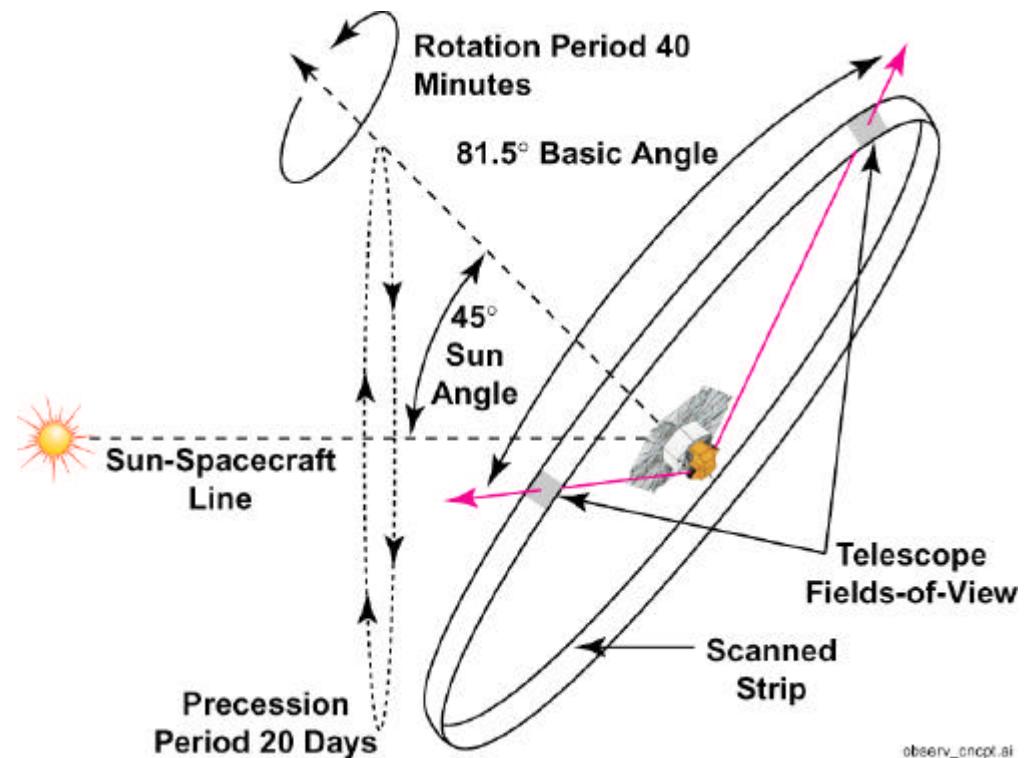
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Top Level Requirements (1 of 3)

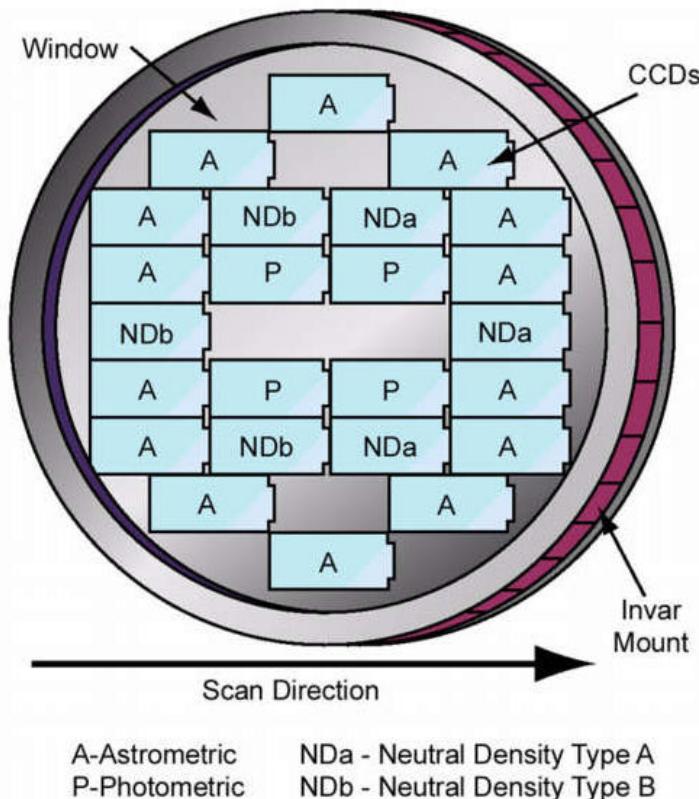


- Science Acquisition Requirements
 - Spin Period: 40 Min +/- 5%
 - Precession Period: 20 Days +/- 10%
 - Sun Angle: 45 +/- 5 Deg





Top Level Requirements (2 of 3)



- **Science Collection Requirements (S/C Attitude Motion)**
 - Spin Rate Variation: +/- 54 marcsec/sec
 - Precession Rate Variation: +/- 600 marcsec/sec
 - Nutation Angle: +/- 10 arcsec
 - Jitter: TBD
- **Science Collection Requirements (Star Image on CCD)**
 - In-Scan Variations:
 $< 1/350\text{th of A Pixel}/1.56 \text{ Sec CCD Crossing Time}$
 - Cross-Scan Variations:
 $< 8 \text{ Pixels}/1.56 \text{ Sec CCD Crossing Time}$



Top Level Requirements (3 of 3)



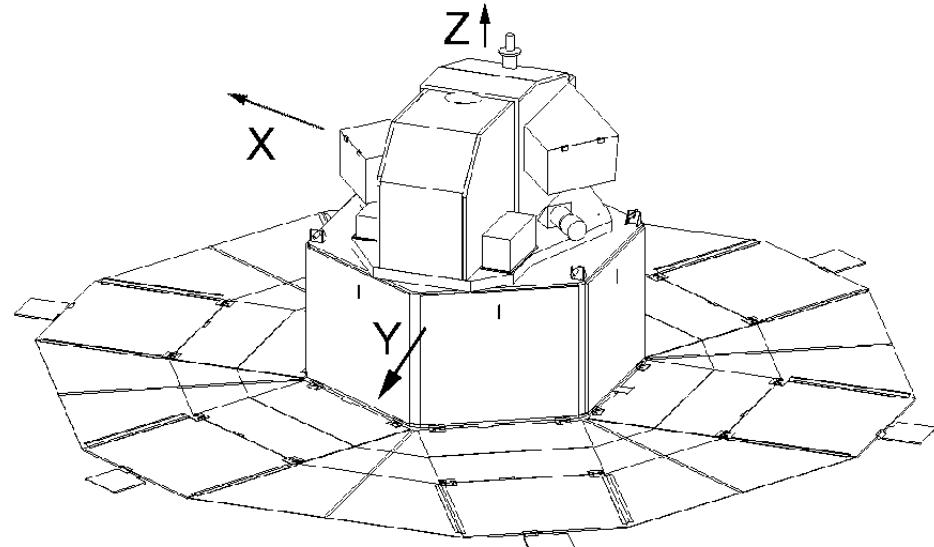
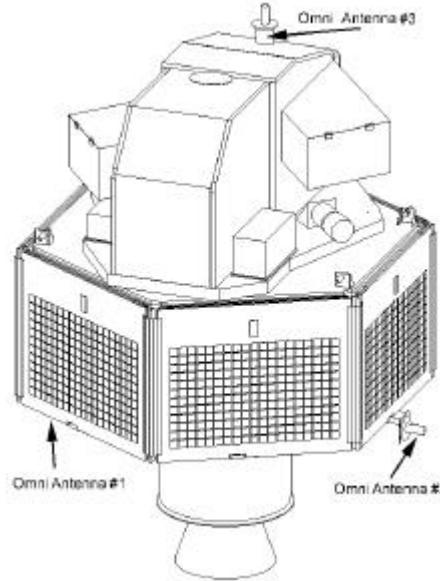
- **Mission Support**
 - Orbit Adjustment
 - AKM Burn
 - Orbit Trim
 - Instrument Protection
- **ADCS Sensor Knowledge (Capability)**
 - Sun Angle: +/- 0.5 deg (+/- 0.25 deg)
 - Inertial Attitude: +/- 10 as (+/- 10 as)
 - Transverse Rate: +/- 2 as/s (+/- 0.2 as/s)
 - Spin Rate: +/- 1 as/s (+/- 0.2 as/s)



Current Baseline/Approach (1 of 3)



On-Orbit Configurations



GEO Transfer Orbit (GTO) or Stowed Configuration

- Standby Mode
- Inertial Pointing Mode
- Sun Pointing Mode (-Y @ Sun)
- Safe Hold Mode
- Open Loop Burn Mode
- Active Nutation Control Mode
- Spin Axis Precession

Operational or Deployed Configuration at GEO

- Standby Mode (Stellar Mapping)
- Inertial Pointing Mode
- Sun Pointing Mode (-Z @ Sun)
- Safe Hold Mode



Current Baseline/Approach (2 of 3)



Attitude Control Modes

Mode	Objective	Measurement Capability	Control Method	ADCS Hardware
Standby	Monitor Sensor Data During Stellar Mapping Operations	Attitude & Body Rates	Passive Solar Precession & Nutation Control	Star Tracker (ST), Inertial Measurement Unit (IMU), Sun Sensor (SS), Nutation Damper (ND) [ST, IMU, SS: Not For Control Feedback]
Inertial Pointing	Hold Any Attitude	Attitude & Body Rates	Attitude & Body Rate Control	ST, IMU, SS, Thrusters
Sun Pointing (CPU)	Points Desired Vehicle Axis To Sun	Sun Vector & Body Rates	Sun Vector & Body Rate Control	IMU, SS, Thrusters
Safe Hold (ACS/RCS Module)	Points Vehicle To Sun	Sun Vector & Body Rates	Sun Vector & Body Rate Control	IMU, SS, Thrusters
Open Loop Burn	Spin Rate Changes, Orbit Trim	Sun Vector & Body Rates	Open Loop Thruster Firings	IMU, SS, Thrusters [IMU & SS: Not For Control Feedback]
Active Nutation Control	Nutation Control At High Spin Rates	Body Rates	Active Nutation Angle Control	IMU, Thrusters
Spin Axis Precession	Precess Spin Axis	Spin Axis Pointing Direction & Roll Orientation	Closed Loop Precession Control	IMU, SS, Thrusters



Current Baseline/Approach (3 of 3)

Standby (Stellar Mapping) Mode



- **Solar Torque Precession**
 - Solar Radiation Pressure Torque Generated by the Sun Shield
 - Fixed Sun Shield Sweep Angle
 - No Active Control
- **Solar Torque Trim**
 - Trim Tab Adjustment
 - Precession/Spin Rate Control
 - Accommodate CG Offset, Spin Axis Misalignment, Optical Property Variation, Sun Shield Deployment Error
 - Precession/Spin Rate Data Needed for Trimming Provided by the Science Instrument



Derived Requirements (1 of 2)



From Science Acquisition Requirements

- Actuator Sizing
 - Thrusters: Number, Size, Minimum Impulse Bit, Locations, etc.
- Attitude Sensor Performance
 - ST, IMU, SS
- Nutation Damping
 - Damper Mechanism, Requirements, etc.
 - Allowable Residual Body Rates

From Science Collection Requirements

- Actuator Sizing
 - Trim Tabs: Number, Size, Location, Range of Motion, Step Size, Degrees of Freedom (DOF), Surface Properties, Flatness, Thermal Radiation
 - Trim Masses: Number, Size, Location, Range of Motion, Step Size, DOF



Derived Requirements (2 of 2)



From Science Collection Requirements (cont.)

- Disturbance Torque Sources
 - S/C Mass Property: CG Offset Tolerance, Cross-Products of Inertia Tolerance (or Spin Axis Misalignment)
 - Gravity Gradient Torque: Transverse Axis/Spin Axis Inertia Ratio
 - Magnetic Torque: Residual Magnetic Dipole
 - Thermal Radiation Torque: S/C Core Radiator, CCD Radiator, Sun Shield
 - Fuel Slosh
 - Earth Albedo and Thermal Radiation
 - Solar Irradiation Variation
 - Jitter
 - Thruster Leakage
- Sun Shield Property
 - Surface Optical Properties: Uniformity and Degradation
 - Orientation and Flatness of Solar Panel and Web
 - AKM Hole Coverage
- Payload Body Rate Knowledge Made Available for Refined Control of Trim Tabs and Trim Masses



Stellar Mapping Performance (1 of 4)

Input Data for the NRL FAME Simulator



Input data	Ideal model	Model A	Model B	Model C
Mass property:				
- Moment of inertia ($\text{kg}\cdot\text{m}^2$)	Ixx=355 Iyy= 355 Izz=361 Ix _y = 0 Ix _z = 0 Iy _z = 0 xCG=0 yCG=0 zCG=0.87	Ixx=355 Iyy= 355 Izz=361 Ix _y = 0 Ix _z = 0 Iy _z = 0 xCG=0 yCG=0 zCG=0.87	(30 as wobble angle) Ixx=355 Iyy= 355 Izz=361 Ix _y = 0 Ix _z = 0 Iy_z= 0.0009 xCG=0 yCG=0 zCG=0.87	(CG offset, Ixx<Iyy) Ixx=350 Iyy= 355 Izz=361 Ix _y = 0 Ix _z = 0 Iy_z= 0.0009 xCG= -0.007 yCG=0.007 zCG=0.871
Sun shield geometry:				
- Solar panels	- 2.29m ² rectangles	- 2.29m ² rectangles	- 2.29m ² rectangles	- 2.29m ² rectangles
- Webs	- 1.66m ² triangles	- 1.66m ² triangles	- 1.66m ² triangles	- 1.66m ² triangles
- Sweep angle	- 6.45 deg	- 6.45 deg	- 6.45 deg	- 6.45 deg
- Core radiator	- 3.13m ² hexagon	- 3.13m ² hexagon	- 3.13m ² hexagon	- 3.13m ² hexagon
- AKM hole	- 0.483m ² circle (covered)	- 0.483m ² circle (covered)	- 0.483m² circle (uncovered)	- 0.483m² circle (uncovered)
- Trim tabs	- 0.15m ² rectangles	- 0.15m ² rectangles	- 0.15m ² rectangles	- 0.15m ² rectangles
- Initial deflection angle	- 1.5 deg	- 1.5 deg	- 1.5 deg with 1% random variation	- 1.5 deg with 1% random variation
Sun shield optical properties	C _s	C _d	Same as ideal model	- 1% random variation on Cs of solar panels, webs, and trim tabs
- Solar panels	0.34	0.02		
- Webs	0.80	0.06		
- Core radiator	0.83	0.10		
- AKM hole	0.83	0.10		
- Trim tabs	0.83	0.10		
Solar irradiation (W/m^2)	1365.5 (constant)	SOHO data with 1 min. samples	SOHO data with 1 min. samples	SOHO data with 1 min. samples
Gravity gradient torque	Assumed zero	Spherical, uniform gravity earth	Spherical, uniform gravity earth	Spherical, uniform gravity earth
- Earth gravity field model				
Magnetic torque	Assumed zero	- 500 pole-cm - Dipole model	- 500 pole-cm - Dipole model	- 500 pole-cm - Dipole model
- S/C dipole moment (pole-cm)				
- Earth magnetic field				

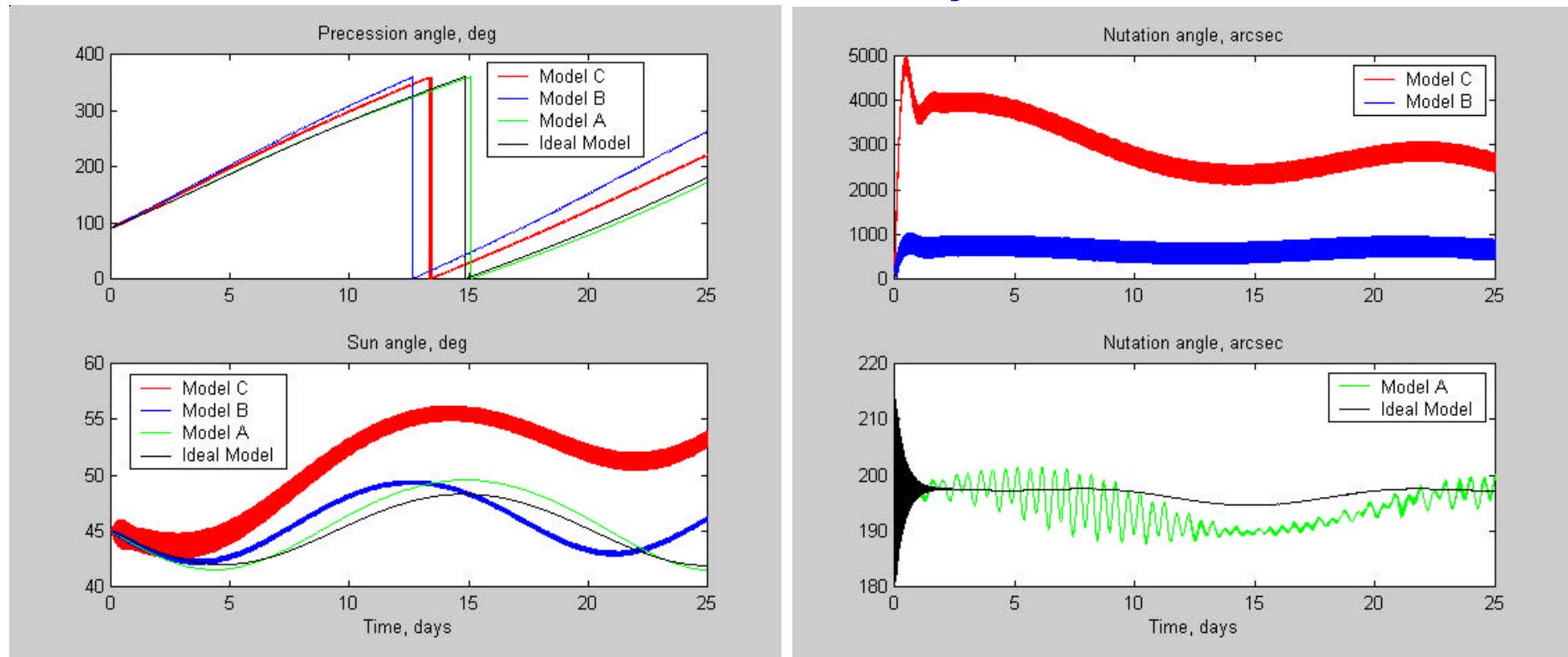
Input data	All Models
Earth albedo and thermal radiation	Assumed zero
S/C thermal radiation torque	Assumed zero
Initial orbit ephemeris data	
- Mean motion	- 360/mean solar day
- Inclination	- 28.7 deg
- Eccentricity	- 0.007115
- Ascending node	- 255 deg
- Argument of perigee	- 0 deg
- Mean anomaly	- 297.741 deg
- GMT Epoch	- July 14, 2004 01:42:47.000
S/C initial attitude and rate	
$-\mathbf{y}_{SF}$	90 deg
$-\mathbf{q}_{SF}$	45 deg
$-\mathbf{f}_{SF}$	0 deg
$-\dot{\mathbf{y}}_{SF}$	1 rev/20 days
$-\dot{\mathbf{q}}_{SF}$	0
$-\dot{\mathbf{f}}_{SF}$	(1 rev/40 min)-(1 rev/20 days)*cos(θ_{SF})
Nutation damper	
- Transverse rate damping constant	Kd=0.01 with a low pass filter at 5e-4 rad/sec



Stellar Mapping Performance (2 of 4)



S/C Attitude Motion Sensitivity to Variations



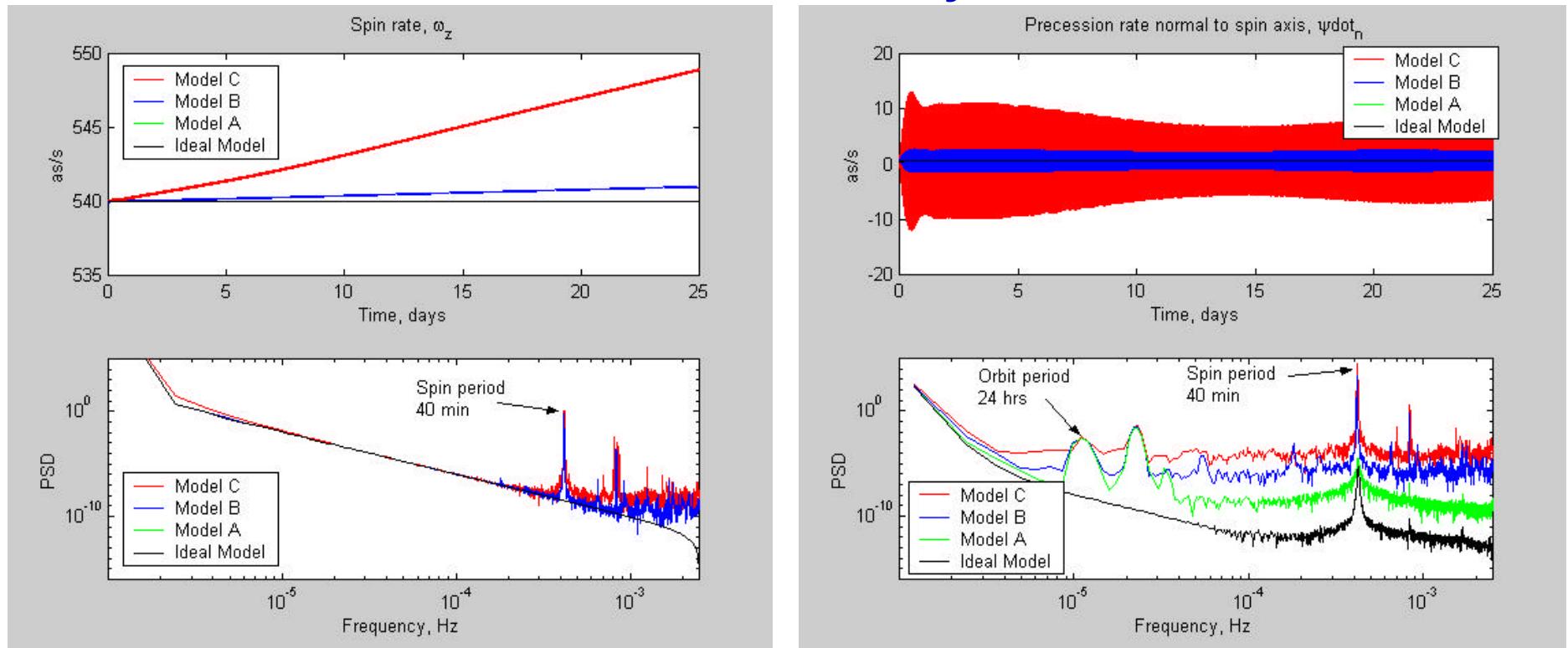
Simulation Models	Precession Period (days, average)	Sun Angle (deg)	Nutation Angle (as)
Ideal	20.28	45.0 bias, ± 3.2 oscillation @ precession period	+196 bias, ± 1.5 oscillation @ precession period
Model A	20.76	45.5 bias, ± 4.0 oscillation @ precession period	+194 bias, ± 0.24 oscillation @ spin, ± 5.6 oscillation @ $\frac{1}{2}$ orbit, ± 3.7 oscillation @ precession periods
Model B	17.20	45.7 bias, ± 3.5 oscillation @ precession, ± 0.16 oscillation @ spin periods	+728 bias, ± 219 oscillation @ spin, ± 3.6 oscillation @ $\frac{1}{2}$ orbit, ± 75.4 oscillation @ precession periods
Model C	18.37	49.6 bias, ± 5.8 oscillation @ precession, ± 0.7 @ spin periods	+3210 bias, ± 219 oscillation @ spin, ± 4.6 oscillation @ $\frac{1}{2}$ orbit, ± 265 oscillation @ precession periods



Stellar Mapping Performance (3 of 4)



In-Scan/Cross-Scan Sensitivity to Variations



Simulation Models	Spin Rate (as/s)	Approx. In-Scan Variation* (pixels)	Precession Rate Normal to Spin Axis (mas/s)	Approx. Cross-Scan Variation** (pixels)
Ideal	540 bias	0	+ 522 bias, ± 4 oscillation @ precession (after initial transients)	± 3.96 (bias), ± 0.03 (precession)
Model A	540 bias	0	+ 515 bias, ± 10 oscillation @ precession, ± 13 @ $\frac{1}{2}$ orbit, ± 0.5 @ spin	± 3.9 (bias), ± 0.08 (precession), ± 0.1 ($\frac{1}{2}$ orbit), ± 0.04 (spin)
Model B	540 initially but ramps up @ + 0.04 per day, ± 0.029 oscillation @ spin	+ 0.3 per day (ramp), $\pm 1/4.5$ oscillation @ spin	+ 600 bias, ± 1740 oscillation @ spin, ± 200 oscillation @ precession	± 4.55 (bias), ± 13.2 (spin), ± 1.57 (precession)
Model C	540 initially but ramps up @ + 0.35 per day, ± 0.058 oscillation @ spin	+ 2.65 per day (ramp), $\pm 1/2.3$ oscillation @ spin	+ 570 bias, ± 7000 oscillation @ spin, ± 750 oscillation @ precession	± 4.32 (bias), ± 53.1 (spin), ± 5.69 (precession)

* $\text{in_scan_variation} = (\text{spin_rate (as/s)} - 540) * 1.56 \text{ (sec)} / .2056640625 \text{ (as/pixel)}$

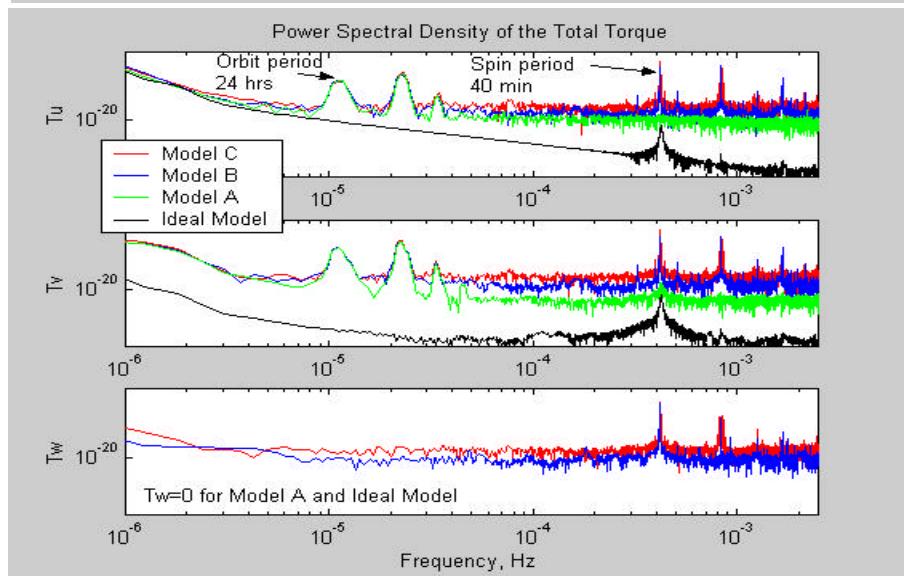
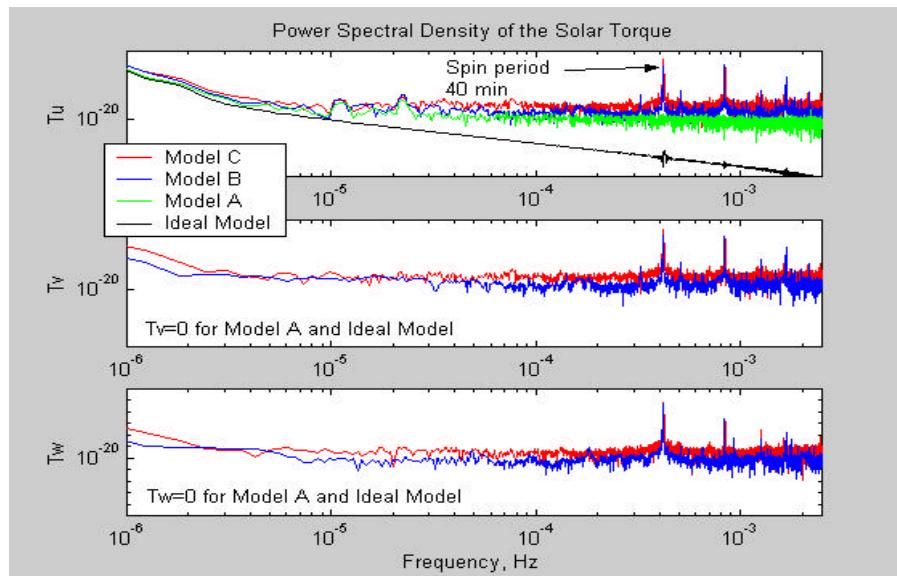
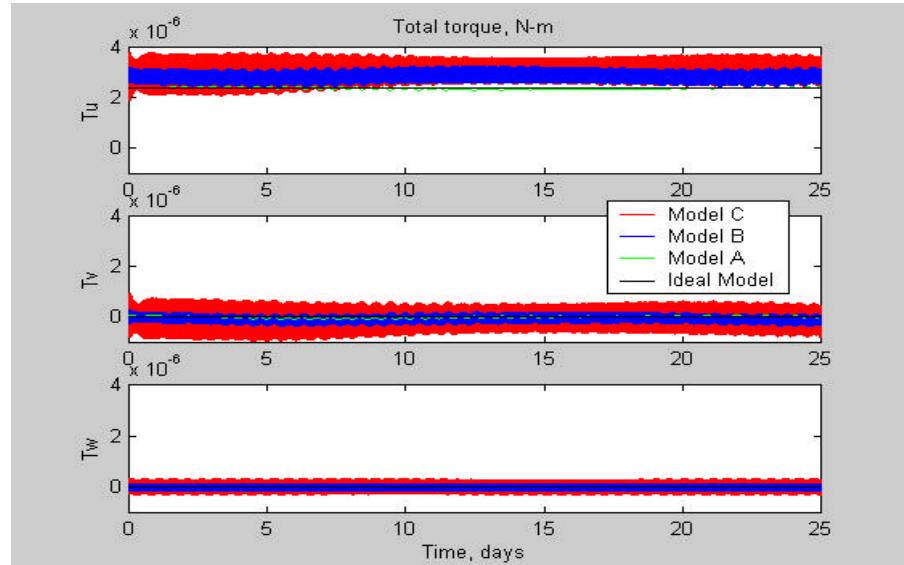
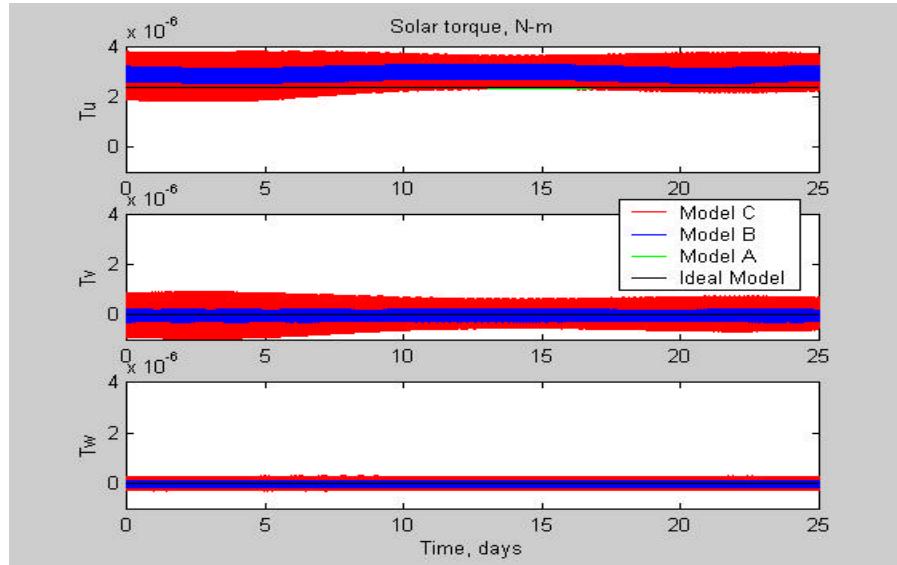
** $\text{cross_scan_variation} = \text{precession_rate_normal_to_spin_axis (as/s)} * 1.56 \text{ (sec)} / .2056640625 \text{ (as/pixel)}$



Stellar Mapping Performance (4 of 4)



Solar Radiation / Other Torque Sensitivity to Variations





Trade Studies



- Sensor (ST, IMU, SS) Selection
 - Performance Requirements, Vendors
- Passive vs. Active Nutation Damping
 - Active Nutation Damping Mechanism
 - Magnetic (Electromagnetic Torquers) vs. Solar (Trim Tabs)
 - Passive Nutation Damping Mechanism
 - Requirements, Build/Buy, Other Inherent Damping (Propellant or Structure)
 - Deployable/Retractable Nutation Damping Mechanism
- Backup Science Acquisition Concept
 - Mass Expulsion (Thrusters) vs. Magnetics (Electromagnetic Torquers) in Comparison to Baseline Concept (Solar Precession)
- Trim Tab vs. Thermal Radiation Patch



Issues / Challenges



- Optical Properties Knowledge (BOL and EOL) and Balancing
- Mass Properties Control: CG Offset, Spin Axis Misalignment
- Thermal Radiation Disturbance Torque Knowledge and Control
- Trim Tab / Trim Mass Control Strategy
- Nutation Damping Mechanism Selection
- S/C Magnetic Dipole Measurement



Top Level Schedule



Activity Name	FY 01				FY 02				FY 03				FY 04				
	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Program Activities																	
Phase B Kick-Off Meeting	◇				◇◇		◇◇										
Reviews	◇																
S/C Bus Complete			◇			◇			◇								
Instrument Delivery To NRL													◇				
System I&T															◇		
Initial Launch Capability																◇	
ADCS Activities																	
ADCS Design																	
Subsystem Concept Definition Update					■■												
Subsystem Requirements Definition																	
Mode Requirements Definition		◇◇															
Hardware Requirements Definition		◇															
Requirements Definition For Other Subsystems		◇															
Control Mode Design, Development & Simulation																	
Imaging Mode (Low Spin Rate) Control System Design		◇◇				◇◇			◇								
SRM Mode (High Spin Rate) Control System Design		◇				◇		◇		◇							
Safe Hold Mode Control System Design		◇				◇		◇		◇							
Attitude Determination Design, Development & Simulation																	
Star Tracker / Inertial Measurement Unit Kalman Filter Attitude Solution		◇				◇		◇		◇							
Sun Sensor / IMU Attitude Solutions																	
High Body Rate Solution		◇				◇		◇		◇							
Low Body Rate Solution		◇				◇		◇		◇							
Dynamics & Materials Analysis, Simulation & Test																	
Dynamics Analysis & Simulation																	
Material/Control System Interaction - Analysis & Test Support																	
Hardware Procurements																	
Star Trackers...					■■■■												
Inertial Measurement Unit						◇		◇		◇							
Sun Sensor...						◇		◇		◇							
Damper..						◇		◇		◇							
Hardware Testing.										◇		■■■■					
Flight Operations Planning Support			◇			◇		◇		◇		◇		◇		◇	
Launch & E&C Support													◇		◇		
	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3